Northwest Africa 773, 2700, 2727, 2977, 3160

Gabbro (with basalt and breccia)

633 (3), 31.7, 191.2 (4), 233, 34 (3) g

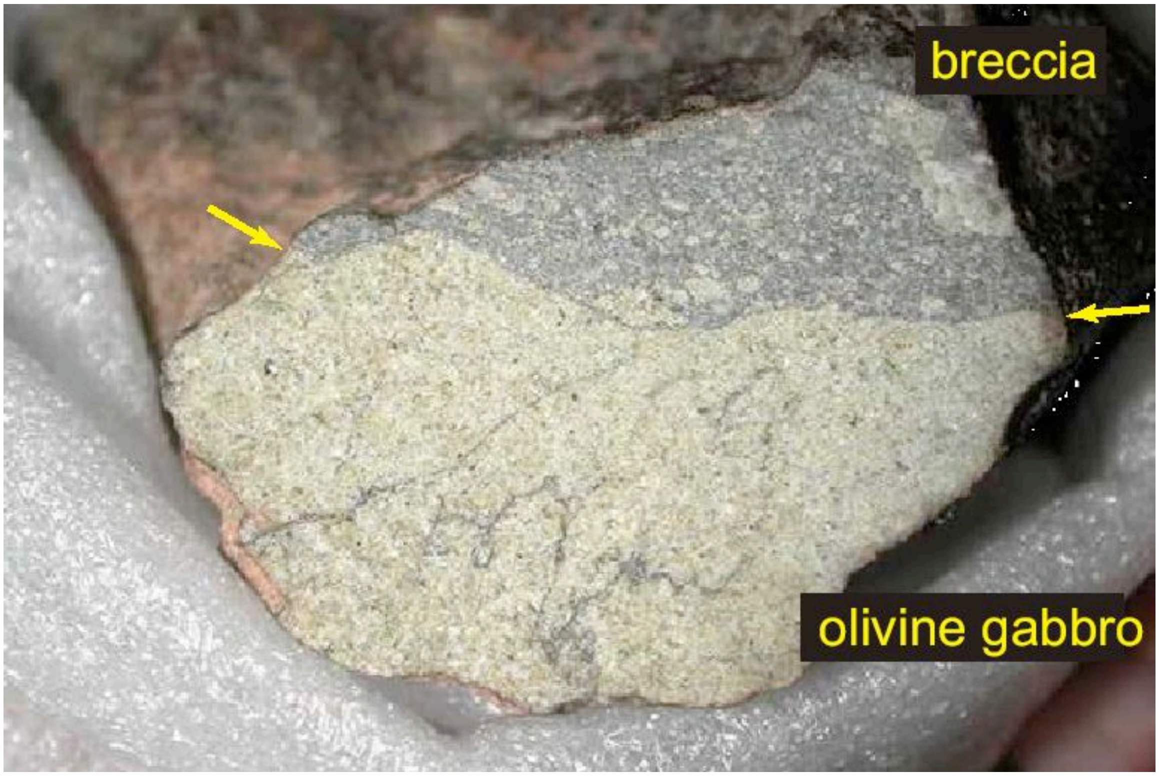


Figure 1: NWA 773 illustrating the olivine gabbro and breccia lithologies.

Figure 2: NWA 2977 which consists entirely of olivine gabbro. Figure 3: NWA 2700 which consists of a gabbroic lithology as well as a darker breccia (both images from Bunch et al., 2006).

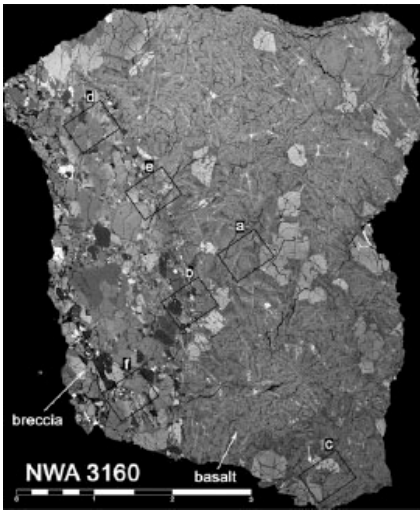
Figure 4: NWA 2727 which contains all four lithologies – basalt (darker clast on right), olivine gabbro (upper left), coarser ferrogabbro (lower left), and breccia (in between all lithologies) (from Bunch et al., 2006).

Introduction

NWA 773 was the first of several stones found in Northwest Africa, all of which appear to be paired based on similar mineralogy, composition and rock types. As more is learned about them, these tentative pairings may need to be revised, but for now it is a very reasonable hypothesis. NWA 773 (three separate stones) contains an olivine gabbro and a breccia lithology (Fig. 1). NWA 2977 contains only the olivine gabbro (Fig. 2). NWA 2700 contains olivine gabbro and breccia, similar to NWA 773 (Fig. 3). NWA 2727 (four separate stones) contains four lithologies – basalt (dominant), olivine gabbro clasts, ferrogabbro, and breccia (Fig. 4). NWA 3160 (three stones) contains a basalt (dominant) and breccia lithology (Fig. 5). A sixth stone, NWA 3333 contains three lithologies – basalt, breccia and the coarse ferrogabbro. Together all four lithologies in these six stones, overlap in mineralogy, texture, and composition.

Petrography and Mineralogy

The olivine gabbro (Fig. 6, 7, 8 and 9) contains approximately 50% olivine (Fo_{64-70}), 30 to 40% pyroxene, and 10-22% plagioclase. The pyroxenes in the gabbro fall into two distinct groups of low and high Ca pyroxenes, whereas the breccia includes these and also more ferroan pyroxenes as are typical for lunar basaltic rocks (Fig. 10). The Ni and Co contents of the olivines are distinct from other lunar basaltic materials (Fig. 11), indicating along with other chemical parameters, that this group of meteorites is different than any previously known. The porphyritic basalt in NWA 2727, 3160 and 3333 contains olivine and chromite phenocrysts.



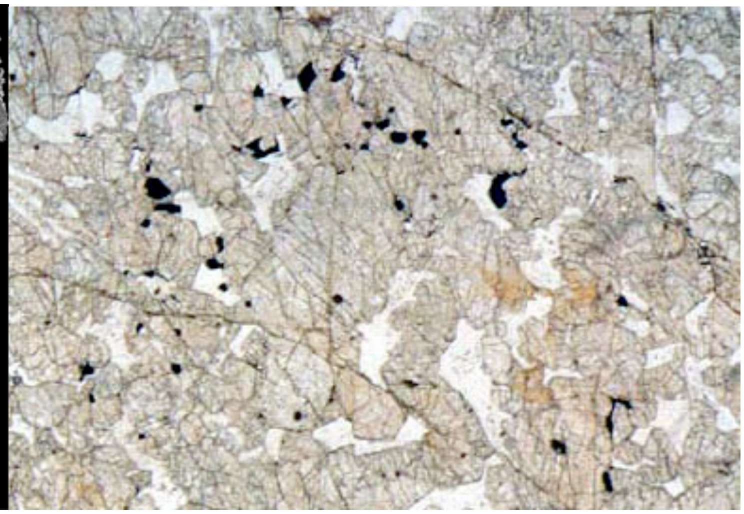


Figure 5: BSE of NWA 3160 illustrating the basalt and breccia lithologies (from Zeigler et al., 2006).

Figure 6: plane polarized light image of olivine gabbro NWA 2977 (from Bunch et al., 2006).

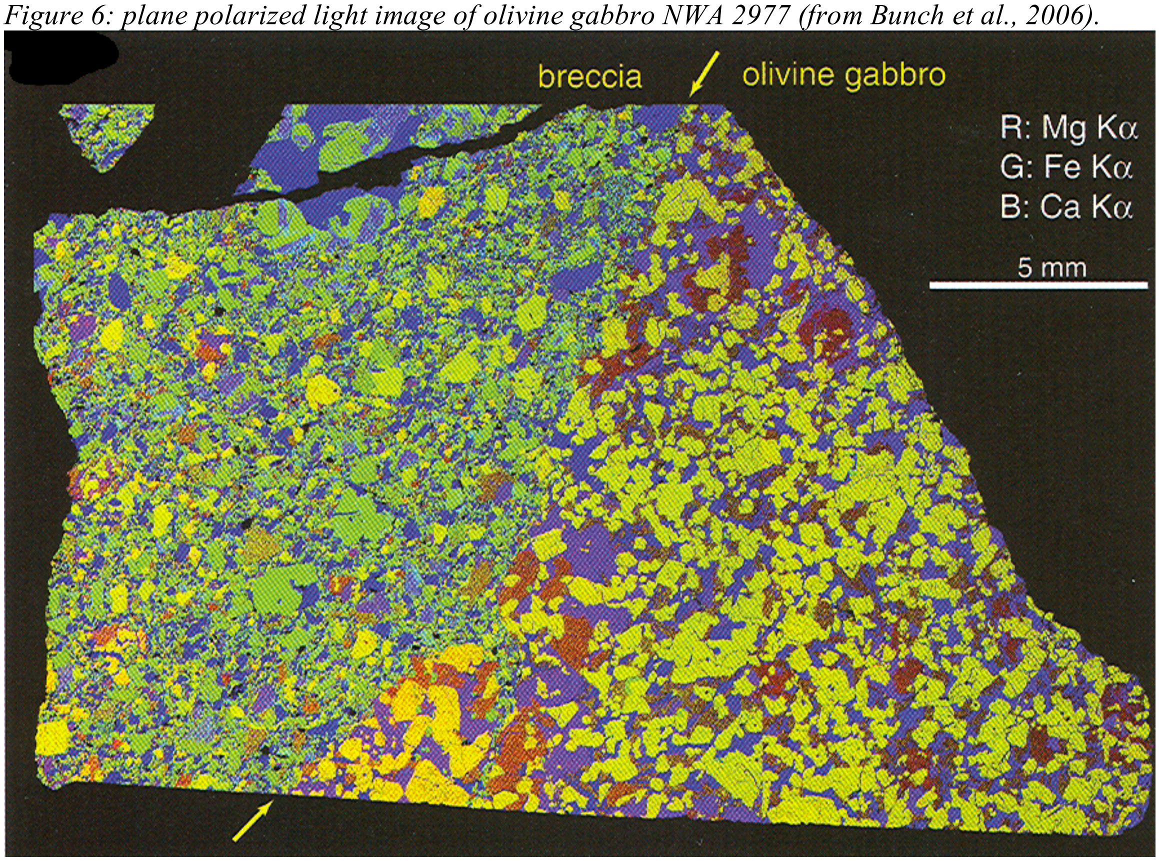


Figure 7: X-ray map of NWA 773 illustrating the breccia and olivine gabbro lithologies (Fagan et al., 2003).

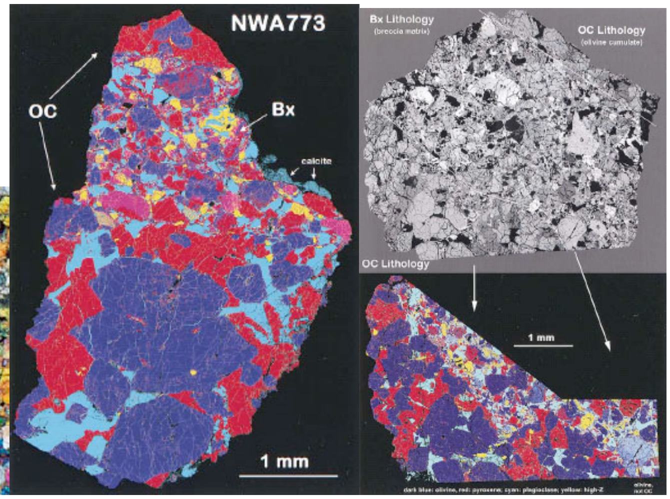


Figure 8: Crossed nicols image of gabbro lithology in NWA 2700 (from Bunch et al., 2006).
Figure 9: X-ray map of NWA 773 illustrating the breccia (bx) and olivine gabbro (OC) lithologies (Jolliff et al., 2003). Inset is BSE image, part of which is the same region as the x-ray map on the right side.

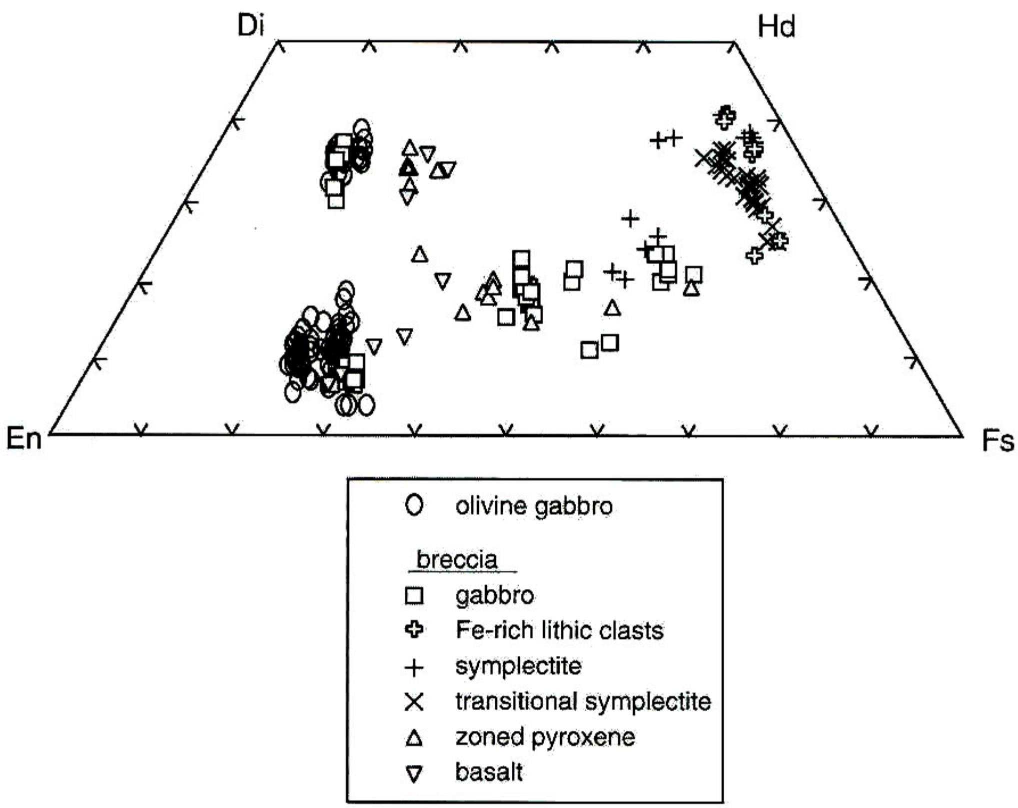


Figure 10: Pyroxene compositions from the olivine gabbro and breccia lithologies of NWA 773 (from Fagan et al., 2003).

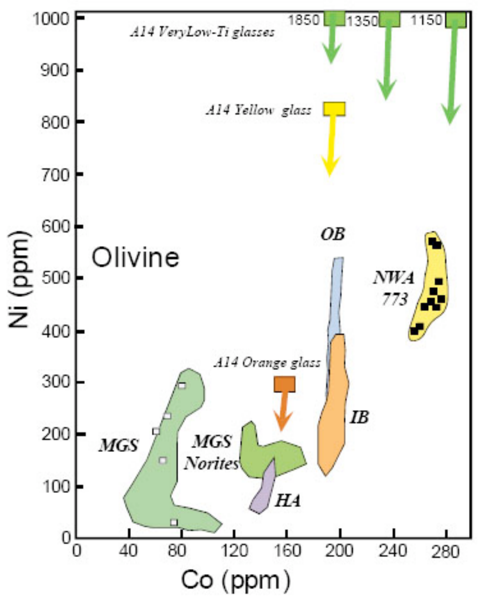


Figure 11: Ni and Co contents of olivines from the gabbro of NWA 773, along with fields for Mg suite (MGS), high aluminum basalt (HA), Apollo 12 olivine basalts (OB), Apollo 15 ilmenite basalts (IB), and Apollo 14 glasses (from Shearer et al., 2005).

Chemistry

The composition of the lithologies in this group (Table 1) is distinctive in several ways. First, the mineralogy of the basalts and gabbros reflects their iron enriched nature. In addition, the breccia and gabbro are LREE enriched, Na and Eu depleted, and are characterized by a high Th/REE ratio (Figs. 12 and 13). In fact, the high FeO and Th have led some (Jolliff et al., 2003) to suggest an origin for these meteorites from near the Procellarum KREEP Terrane or in the Oceanus Procellarum, on the near side of the Moon. In addition, the melt calculated to be in equilibrium with the pyroxene and plagioclase in the gabbro, has KREEPy characteristics, and has some similarity to Apollo 14 green glasses (Jolliff et al., 2003).

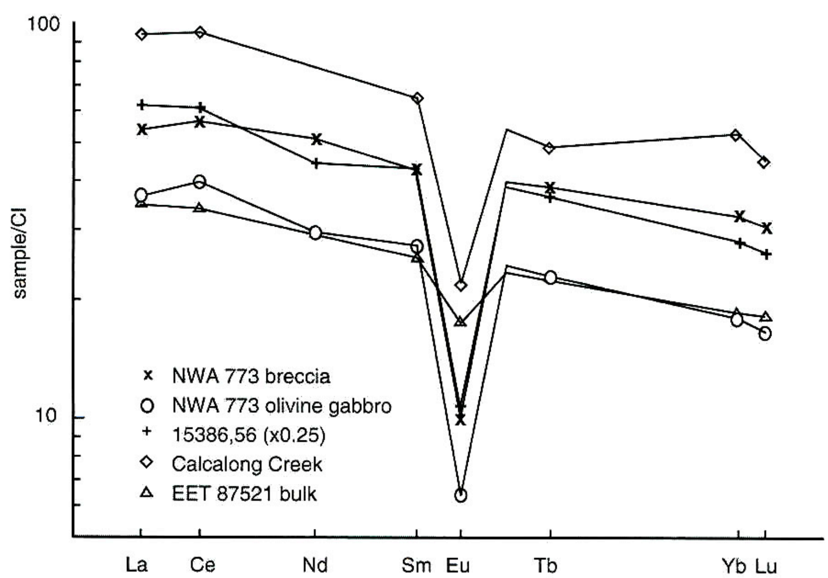


Figure 12: Rare earth element patterns for the breccia and olivine gabbro lithologies of NWA 773, illustrating the LREE enriched nature of NWA, as well as the intermediate concentrations between Calcalong Creek (mingled), KREEP, and EET 87521.

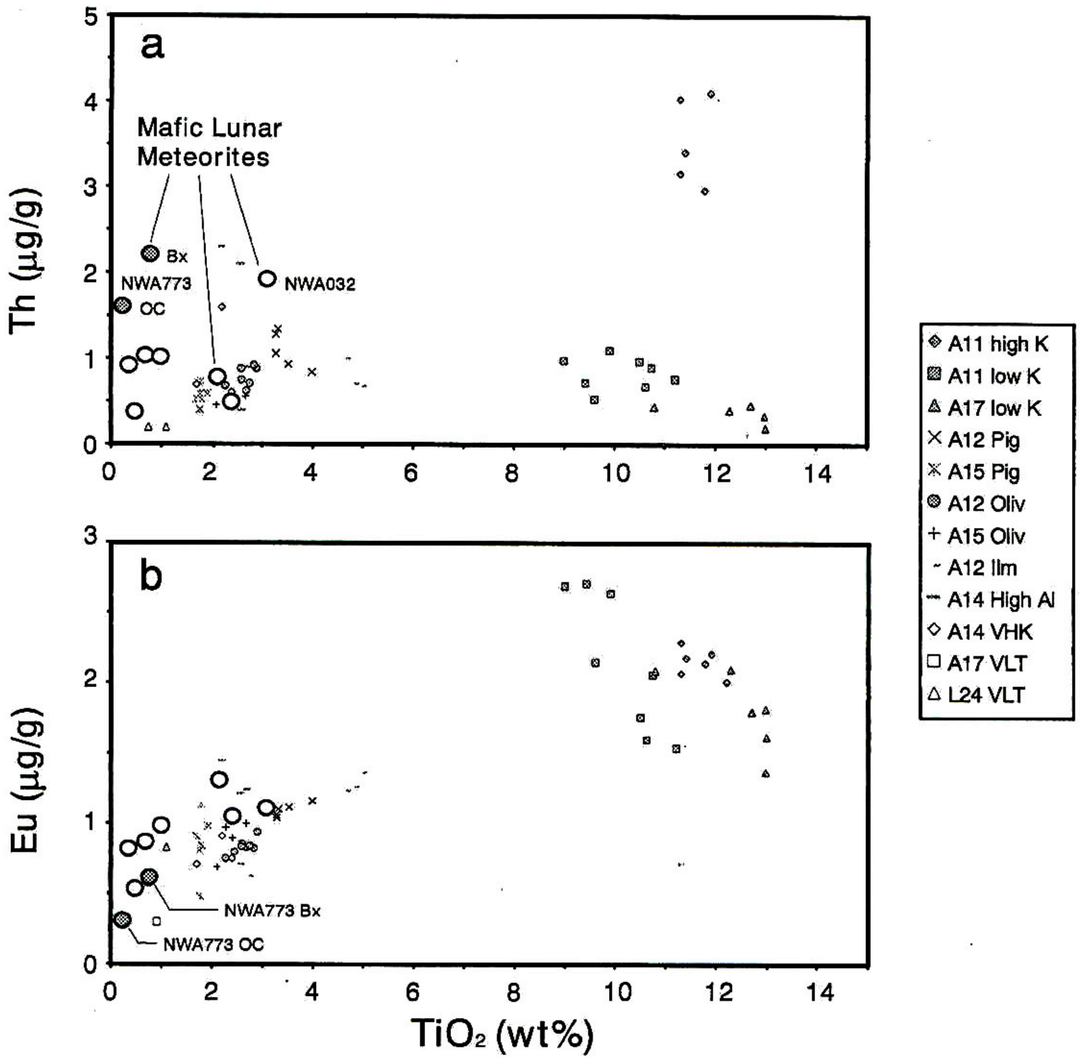


Figure 13: Eu, Th and TiO_2 contents of the NWA 773 olivine gabbro and breccia, showing the low Eu and high Th compared to many lunar basalts, as well as the low Ti contents typical of low Ti basalts.

Radiogenic age dating

Limited age dating of materials from NWA 773 has yielded the youngest ages measured for lunar basalts in the lab. For example, ^{39}Ar-^{40}Ar age determinations for olivine gabbro (cumulate) and breccia lithologies from NWA 773 (from Fernandes et al., 2003) yield 2.67 and 2.94 Ga (Fig. 14). Sm-Nd dating of whole rock and mineral separates from olivine gabbro (Borg et al., 2004) yields an age of 2.865 Ga, in agreement with the Ar ages (Fig. 15). Borg et al. (2004) further suggest that KREEP may be a possible heat source for the young volcanism measured in the NWA 773 samples (Figs. 16 and 17).

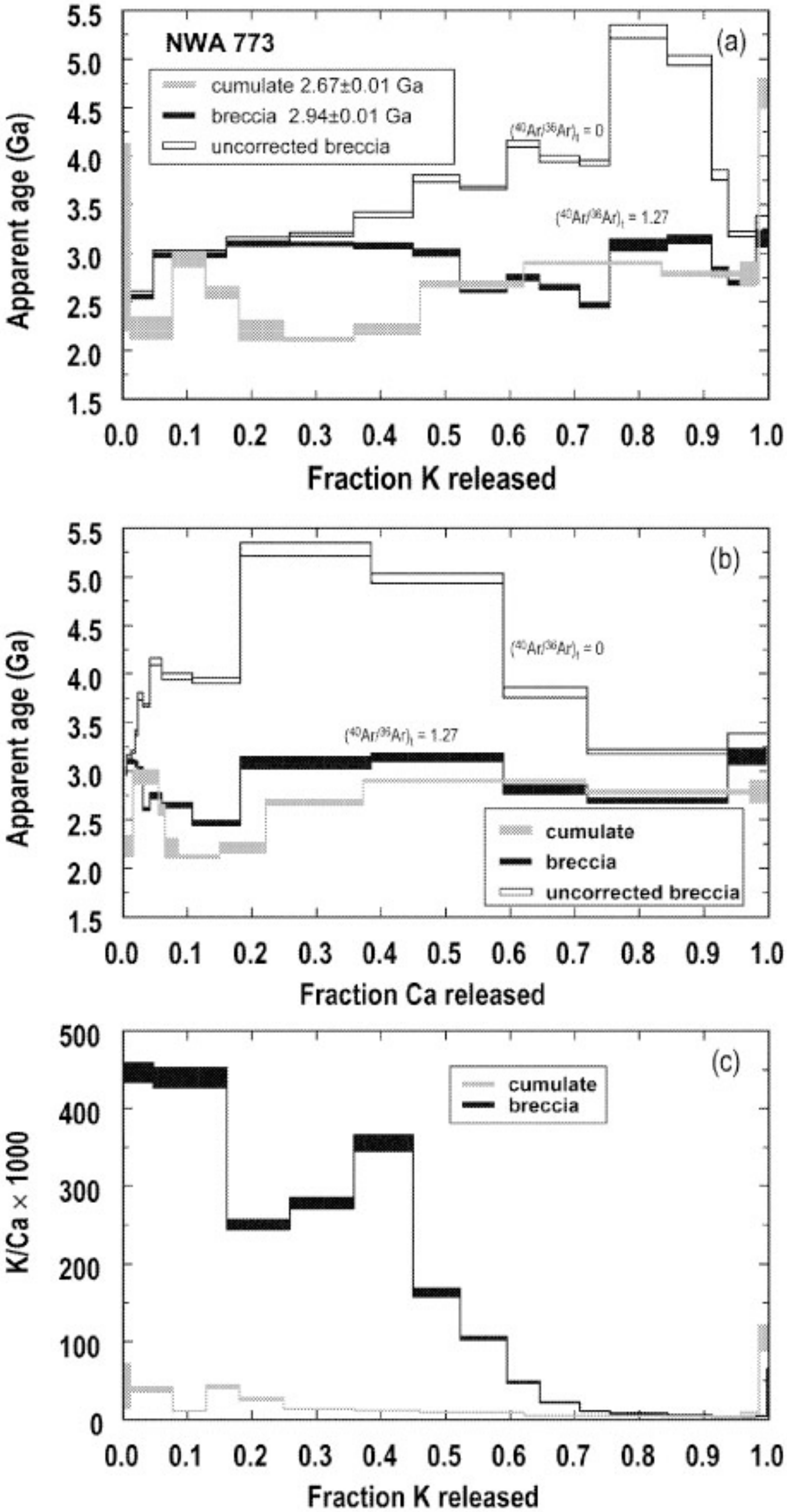


Figure 14: ^{39}Ar-^{40}Ar age determinations for olivine gabbro (cumulate) and breccia lithologies from NWA 773 (from Fernandes et al., 2003).

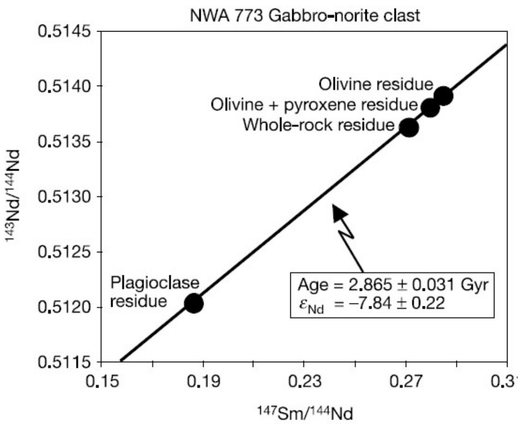
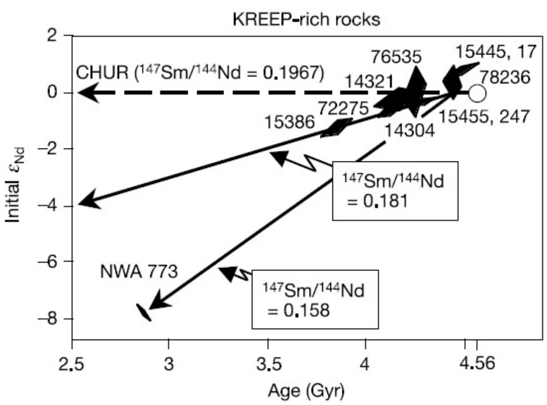


Figure 15: Sm-Nd isochron for gabbro whole rock and mineral separates (from Borg et al., 2004).



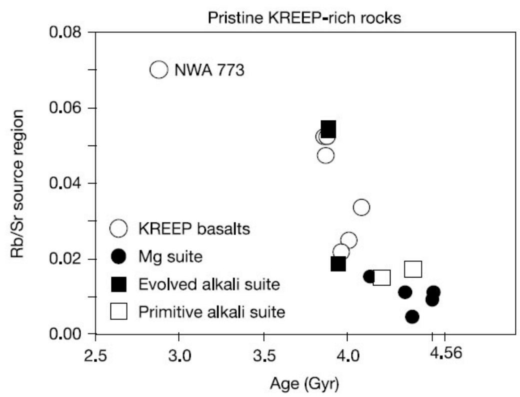


Figure 16: Sm-Nd modeling of source region for NWA 773 indicates derivation from the most LREE enriched (low epsilon Nd) source known for lunar materials (from Borg et al., 2004).

Figure 17: Rb-Sr of source region versus age (Ga) for lunar materials (including NWA 773) suggests that KREEP is a possible heat source for lunar melting (from Borg et al., 2004).

Cosmogenic isotopes and exposure ages

Cosmic ray exposure age dating of NWA 773 lithologies using noble gases has resulted in lunar regolith residence ages of 154 Ma and ~160 Ma, by Fernandes et al. (2003) and Lorenzetti et al. (2005), respectively (Fig. 18).

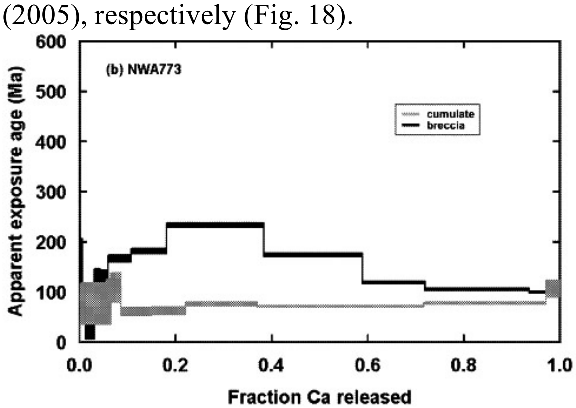


Figure 18: Exposure age for breccia and olivine gabbro lithologies from NWA 773 (from Fagan et al., 2003).

Table 1a. Chemical composition of Northwest Africa 773

reference	1	1	1	2	2
	oliv gabbro	clast	breccia	breccia	OC
weight	39.41	14.46	23.47	108.22	46.04
method	e,g	g	e,g	g	g
SiO_2 %	42		45.7		
TiO_2	0.4		0.84		
Al_2O_3	5.3		8.16		
FeO	20.5		19.8	18.14	19.96
MnO	0.24		0.272		
MgO	25.5		14.16		
CaO	4.8(5.0)	5.4	8.92(8.6)	11.3	5.7
Na_2O	0.15(0.15)	0.16	0.216(0.224)	0.24	0.13
K_2O	0.25(0.073)	0.066	0.111(0.117)	0.12	0.1
P_2O_5			0.12		
S %					
sum					
Sc ppm	23.1	22.2	38.5	37.1	19.5
V					
Cr	5474(2484)	1628	2942(2751)	3004	1366
Co	86	86.9	61.7	58	92
Ni	195	219	115	114	236
Cu					
Zn				28	16
Ga					
Ge					
As				0.38	0.06
Se					
Rb				1.5	
Sr	40	<90	71	96	50
Y					
Zr	157	110	183	187	160
Nb					
Mo					
Ru					
Rh					
Pd ppb					
Ag ppb					
Cd ppb					
In ppb					
Sn ppb					
Sb ppb				30	20
Te ppb					
Cs ppm	<0.15	<0.09	0.136	0.13	0.07
Ba	147	98	156	201	120
La	8.63	8.54	12.6	14.2	10.1
Ce	24.1	23.2	34.1	36.9	25.7
Pr					

Nd	13.6	15	23	21.9	14.8
Sm	4.06	4.05	6.29	6.51	4.22
Eu	0.359	0.355	0.561	0.6	0.29
Gd					
Tb	0.832	0.839	1.4	1.31	0.82
Dy					
Ho					
Er					
Tm					
Yb	2.92	2.85	5.27	4.53	2.63
Lu	0.406	0.39	0.752	0.62	0.37
Hf	3.7	3	4.7	4.62	3.72
Ta	0.367	0.372	0.553	0.54	0.45
W ppb			470	400	
Re ppb					
Os ppb					
Ir ppb	<2.5	<3	<3	0.2	
Pt ppb					
Au ppb	<1.4	<2.8	<2.1	2.1	0.1
Th ppm	1.16	1.26	1.98	2.19	1.58
U ppm	0.36	0.32	0.52	0.59	0.37

technique (a) ICP-AES, (b) ICP-MS, (c) IPAA, (d) PGA, (e) EMPA, (f) RNAA, (g) INAA, (h) wet chemistry

Table 1b. Light and/or volatile elements for Northwest Africa 773

Li ppm					
Be					
C					
S					
F ppm					
Cl					
Br				0.4	0.2
I					
Pb ppm					
Hg ppb					
Tl					
Bi					

References: 1) Fagan et al. (2003); 2) Jolliff et al. (2003)